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GROWTH OF OAK REPRODUCTION INCREASED BY SHELTERWOOD TREATMENTS IN NORTHERN ARKANSAS[1]

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Abstract—Nine-year survival and growth of oak (*Quercus alba* L., *Q. rubra* L., and *Q. velutina* Lam.) reproduction was evaluated in upland oak stands representing a range in site quality, residual overstory stocking, and understory treatments. Analysis of variance was used to test for differences in establishment, survival, and growth of oaks and other species groups as affected by site quality, overstory stocking, and intensity of understory treatment. Establishment of new oak reproduction was not significantly affected by study treatments. However, survival and growth of new and original oak reproduction and change in oak stocking values were significantly affected by the intensity of understory treatment.

INTRODUCTION

Mixed oak types occupy most of the upland commercial forest in northern Arkansas, and oaks are the dominant timber species. However, oak reproduction may not adequately replace present stands, especially on the more productive sites (Graney 1989, Graney and Rogerson 1985). Although declines in oak dominance may result in greater species diversity, the oaks are prized for their timber and wildlife values.

Commercially desirable fast-growing species such as yellow-poplar (*Liriodendron tulipfera* L.) do not occur in western Arkansas, and valuable species such as black walnut (*Juglans nigra* L.), black cherry (*Prunus serotina* Ehrh.), and white ash (*Fraxinus americana* L.) occur infrequently and primarily on the more productive sites. Because most associated species in these upland stands are either slower growing or of lower economic value than the oaks, it is important to ensure that oaks will be a major component of new stands after harvest.

The oak component of future hardwood stands depends on sprouts from cut overstory stems and large oak advance reproduction present at time of harvest (Loftis 1990a, Sander and Clark 1971, Sander and others 1984). Newly established oak seedlings grow too slowly to compete successfully after harvest (Sander and Clark 1971). In contrast, large oak advance reproduction grows rapidly after harvest and has a high probability of becoming dominant in the new stand (Loftis 1990a, Sander and others 1984).

Upland hardwood stands in the Boston Mountains of northern Arkansas may have more than 1,000 stems per acre of oak advance reproduction, but most are <1 ft tall and larger reproduction is often absent. Many of these stands are mature and fully stocked and have well-developed understories of shade-tolerant noncommercial species. Given the size and status of existing reproduction, new stands that develop after harvest will almost certainly contain a low proportion of oak. Researchers are trying to stimulate the growth of small advance reproduction using shelterwood treatments with light to medium overstory cutting plus partial to complete understory control (Graney 1989, Loftis 1990b, Sander 1987, Sander and Graney 1993).

Variants of the shelterwood method for regenerating oaks have shown promise in the Missouri Ozarks (Schlesinger and others 1993), and the Southern Appalachians (Loftis 1990b). In these studies, development of oak reproduction on medium and good quality sites has been enhanced.

Graney and Murphy (1995) described the 9-year height development of individual white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam), white ash, and black cherry stems as influenced by study treatments and initial stem size. This paper reports the 9-year effects of the various overstory and understory shelterwood treatments on mortality and density of original reproduction of oaks and other species groups and the growth and mortality of new oak reproduction established after treatment. The effects of the shelterwood treatments on changes in oak regeneration stocking values over the 9-year period are also evaluated.

PROCEDURES

Study Region

The Boston Mountains are the highest and most southern of the Ozark Plateaus physiographic province. They form a band 30 to 40 mi wide and 200 mi long from north-central Arkansas westward into eastern Oklahoma. Elevations range from about 900 ft in the valley bottoms to 2,500 ft at the highest point. The plateau is sharply dissected, with most ridges flat to gently rolling and generally <0.5 mi wide. Mountainsides consist of alternating steep simple slopes and gently sloping benches.

Soils on mountaintops and slopes usually have shallow to medium depth and are represented by medium-textured members of the Hartsells, Linker, and Enders series (*Typic Hapludults*). They are derived from sandstone or shale residuum, and their productivity is medium to low. In contrast, soils on mountain benches are deep, well-drained members of the Nella and Leesburg series (*Typic Paleudults*). They developed from sandstone and shale colluvium, and their productivity is medium to high. Rocks in the area are alternating horizontal beds of Pennsylvanian shales and sandstones. Annual precipitation averages 46 to 48 in., and March, April, and May are the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

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Study Description

Six mature upland hardwood stands were selected for study at three locations in the Ozark National Forest. Three stands are on upper north- or east-facing slopes with site indices of 57 to 63 ft (mean=60 ft) for northern red oak, base age 50 years. The other three stands are on north- or east-facing mountain benches with northern red oak site indices of 72 to 80 ft (mean=75 ft). Mean age for upper slope stands was 74 years (range=72-84 years), while stands on mountain benches averaged 78 (range=70-84) years. Six plots (approximately 1 acre in size) were established in each stand. Overstory (stems ≥1.6 in. d.b.h.) densities were reduced to either (1) 40 or (2) 60 percent relative stocking density (Gingrich 1967). Understory (stems <1.6 in. d.b.h.) treatments were: (1) kill all competing stems (intensive), (2) kill all competing stems >5.0 ft tall (partial), or (3) no understory treatment. The six overstory-understory treatment combinations were randomly assigned to each plot.

Pretreatment overstory stocking for all plots averaged 106 percent and basal area averaged 118 ft^2 per acre (table 1). The overstory was cut from below. After all subcanopy stems ≥1.6 in. d.b.h. were removed, the overstory canopy was cut to the prescribed stocking goal. Stumps of all less-desirable (slow growing or noncommercial) overstory stems were sprayed with 2,4-D plus picloram to reduce sprouting. Overstories on all plots were predominantly oak. Northern red, black, and white oaks accounted for 80 percent of the overstory stocking before treatment and more than 90 percent after treatment. Ash and cherry represented less than 1 percent of the stocking on all plots.

Understory control treatments were imposed by cutting target stems near ground level and spraying stumps with the 2,4-D plus picloram herbicide immediately after cutting.

Understory treatments were completed in May 1980, and overstories were cut May through July 1980. Understories on upper slope sites (site index 60) were dense mixtures of tolerant brushy or less-desirable species such as red maple (*Acer rubrum* L.), serviceberry (*Amelanchier arborea* Michx. F. Fern), redbud (*Cercis canadensis* L.), and blackgum (*Nyssa sylvatica* Marsh.). Dogwood (*Cornus florida* L.), hophornbeam (*Ostrya virginiana* (Mill.) K. Koch.),pawpaw (*Asimina triloba* L.), and sugar maple (*Acer saccharum* Marsh.) were common on bench sites (site index 75).

Reproduction was measured on a series of sixteen 1/735-acre subplots systematically distributed across the interior 0.25 acre of each plot. On each subplot, all reproduction <1.5 in. d.b.h. was tallied by species and 1-ft height classes. In addition, all oak stems were identified and mapped for remeasurement. For these stems, height and basal diameter (1 in. above groundline) were measured to the nearest 0.1 ft and 0.1 in., respectively. Reproduction was measured before treatment and 1, 3, 5, and 9 years after treatment.

Data Analysis

The study was laid out as a randomized block split-plot design. There were three locations or blocks, with the upper slope of each block corresponding to site index of 60 and the lower slope to site index of 75. Within each site index (whole plot) area, six subplots were established and randomly assigned one of the six experimental treatment combinations. The treatment combinations involved the residual stocking density (40 and 60 percent) and understory control (intensive, partial, and no control). Analysis of variance was used to compare expressions of reproduction response and stand conditions among treatments. Differences among treatment means were isolated by using the Ryan-Einot-Gabriel-Welsch Multiple Range Test (α=0.05) (SAS Institute 1989).

Table 1—Overstory values per acre for original stand after treatment and 9 years after treatment

	Original stand		After treatment		Year 9	
Stocking treatment	Basal area mean range	Stocking mean range[a]	Basal area mean range	Stocking mean range[a]	Basal area mean range	Stocking mean range[a]
	Ft^2	*Percent*	*Ft^2*	*Percent*	*Ft^2*	*Percent*
			Site index = 60 feet			
40 percent	118 (110–127)	108 (110–115)	51 (45–54)	41 (40–42)	63 (57–69)	50 (45–53)
60 percent	119 (107–126)	108 (98–115)	72 (69–76)	59 (57–61)	84 (77–88)	67 (63–70)
			Site index = 75 feet			
40 percent	114 (110–124)	103 (100–108)	51 (45–54)	40 (38–42)	59 (53–67)	47 (42–51)
60 percent	118 (112–130)	106 (102–120)	73 (69–81)	58 (57–60)	82 (75–93)	64 (60–70)

[a] Based on stocking equation from Gingrich (1967).

RESULTS AND DISCUSSION

Advance Reproduction Before Treatment

The pretreatment height distribution of advance reproduction on study plots was typical of well stocked mature upland oak stands in the Boston Mountains (table 2). Total oak, ash, and cherry reproduction and advance reproduction >1 ft tall are greatest on less productive upland sites. Large advance reproduction (>5 ft) is often sparse or absent. Most of the oak reproduction is <1 ft tall and few stems are >2 ft tall. Ash and cherry reproduction is highly variable throughout the Boston Mountains but is usually most abundant on medium to good sites. Although ash and cherry are minor components of the overstory in these upland stands, they represent the majority of the desirable species reproduction >2 ft tall.

Table 2—Mean height distribution per acre of reproduction by species group before treatment

Species	Height class (feet) <1	2	3	4	5	>5
	Number of stems					
	Site index = 60					
Oaks[a]	1,959	106	15	13	5	0
Ash & cherry	930	222	143	72	41	5
Other species	4,341	2,910	1,346	1,187	905	1,569
	Site index = 75					
Oaks[a]	1,243	61	18	8	5	0
Ash & cherry	452	179	74	38	31	5
Other species	4,813	2,387	1,523	1,153	1,160	1,408

[a] White, black, and northern red oaks.

The other species group (table 2) is dominated by tolerant, brushy, and noncommercial species; hickories (*Carya* spp.); and other less common species that would be considered acceptable stocking on selected sites.

Reproduction After Treatment

Nine years after shelterwood cutting, reproduction size and abundance indicated little or no response to site quality or the overstory density treatments. Number of small (<1.1 ft) oak and other species stems were greater in stands cut to 60 percent overstory stocking but number of stems in the larger height classes were not affected by the 40- or 60-percent overstory stocking densities (table 3). Graney (1989) reporting 5-year response to the overstory density treatments found that numbers of ash, cherry, and other species stems in the 1.1 - 5.0 and >5.0 ft height classes were significantly greater in stands cut to 40 percent stocking. However, this initial response did not persist through the 9-year period. The effect of overstory density on reproduction development may have been modified by overstory mortality that resulted from the severe drought in the 1980 growing season. While most overstory mortality occurred in 1980, some stems that survived in poor condition died over the next 2 to 4 years. As a result of this mortality, stocking in the 40 percent treatment increased from 40 percent in 1980 to 50 percent in 1988 while the 60 percent stands increased from 59 percent to 66 percent over the same period.

Control of competing understory stems produced the greatest response in oak reproduction height development of all the study treatments. Stands receiving the intensive and partial understory treatments produced significantly more oak stems in the medium and large reproduction height classes than stands receiving no understory control (table 3). Numbers of ash and cherry stems in the small, medium, and large height classes did not differ significantly among the three understory treatments. After 9 years, effects of understory control on numbers of other species were only apparent in the large height class. Stands receiving the most intensive understory treatment had significantly fewer stems >5 ft tall than those receiving intermediate and no control treatments (table 3).

The primary objective in applying the shelterwood method in mature upland oak stands is to develop a sufficient amount of oak advance reproduction large enough to successfully compete after overstory removal. This objective may be accomplished through establishment and growth of new seedlings, enhanced development of small pre-established stems, or both. In this study, the overstory/understory density control treatments increased the average size of oak, ash, and cherry reproduction. The numbers of oak stems >1 ft tall also increased from about 100 per acre before treatment to more than 1,000 per acre in stands with partial or intensive treatment. The number of ash and cherry stems >1 ft tall increased by 400 to 600 per acre after

Table 3—Reproduction 9 years after treatment as affected by residual stocking and understory treatment

Species and height class	Pretreatment	Residual stocking (percent) 40	60	P>F	Understory treatment 1[a]	2	3	P>F	Mean square error
Feet				*Number of stems*					
Oaks[b]									
<1.1	1,601	1,030	1,750*[c]	0.03	1,440	1,496	1,323	0.77	8.95E5
1.1-5.0	115	590	919	.23	1,054*	897*	313	.05	6.33E5
>5.0	0	95	92	.93	139*	123*	19	.01	9.32E3
Ash and cherry									
<1.1	691	368	140	.34	155	124	483	.40	4.90E5
1.1-5.0	400	726	484	.21	684	501	629	.71	3.08E5
>5.0	5	432	256	.09	360	335	337	.97	8.67E4
Other species									
<1.1	4,577	1,350	1,855*	.05	1,513	1,592	1,703	.81	5.13E5
1.1-5.0	6,286	5,285	5,911	.28	5,571	5,762	5,461	.91	2.90E6
>5.0	1,488	4,389	3,621	.11	2,879	4,528*	4,609*	.05	1.91E6

[a] 1 = All stems treated; 2 = stems >5 ft treated; 3 = no treatment.
[b] White, black, and northern red oaks.
[c] Stocking or understory means in rows followed by * are significantly different at $\alpha = 0.05$.

treatment. Most of the increase in oak reproduction >1 ft tall resulted from smaller pretreatment stems and new reproduction growing into the 2- and 3-ft height classes (table 4). Height development of surviving pretreatment oak and ash reproduction was significantly affected by initial stem height and intensity of understory control. Greatest height growth was produced by large (4 to 5 ft) stems on plots with the intensive control treatment. However, small oak and ash stems (<1 ft) also responded to understory control and grew into the 2- or 3-ft height classes over the 9-year period (Graney and Murphy 1995).

Black cherry produced the greatest height growth response to the overstory and understory treatments. Cherry reproduction >5 ft tall developed from pretreatment seedlings and seedling sprouts >1 ft tall. Stems in the 2- to 5-ft classes developed from stems <1 ft tall before treatment and from new seedlings established after treatment (table 3). While no study treatments were statistically significant in terms of total numbers of stems by height class groups (table 3), height growth response of individual pretreatment cherry stems was strongly influenced by overstory and understory treatments as well as site quality. Nine-year height growth ranged from about 3 ft for the smallest stems in stands on the most productive sites thinned to 60 percent overstory stocking with no understory control to >12 ft for large stems on average sites thinned to 40 percent stocking with intensive competition control (Graney and Murphy 1995).

Redevelopment of the competing understory varied considerably with the intensity of the overstory and understory treatments. On plots cut to 60 percent stocking with the intensive understory treatment, redevelopment of competing understory was very slow. Stems of desirable species in all size classes were essentially free to grow for the first 5 years after treatment. Although numbers of competing stems increased considerably over the 9-year measurement period only the smallest desirable stems were overtopped after 9 years. However, on plots cut to 40 percent stocking, the intensive control treatment was effective only for about 5 years. By the end of the fifth year, most of the small oak stems were overtopped and by the ninth year only ash and cherry stems initially >3 ft tall were free to grow.

The partial (>5 ft) understory control increased growth of oak reproduction, but its effect probably will not continue much beyond the ninth year. Understory development was most pronounced on plots cut to 40 percent stocking where all small oak stems and most large stems were overtopped by competing stems.

Overstory cutting (stems ≥1.6 inches) resulted in height growth response of ash and cherry reproduction but only the largest oak stems increased in height. After 9 years, all oak and most of the ash and cherry reproduction were overtopped by competing stems.

Table 4—Mean height distribution per acre of original and new oak reproduction 9 years after understory treatment

Understory treatment[a]	Height class (feet) <1	2	3	4	5	>5
	Number of stems					
Original oaks						
Pretreatment	1,601	84	16	10	5	0
1[b]	414	361	90	67	39	88
2	414	295	103	54	47	61
3	341	161	42	27	4	0
New oaks[c]						
1	1,026	389	93	12	4	51[d]
2	1,082	369	17	8	4	62
3	892	72	7	0	0	19

[a] 1 = All stems treated; 2 = stems >5 ft treated; 3 = no treatment.
[b] White, black, and northern red oaks present before treatment.
[c] White, black, and northern red oaks established after treatment.
[d] New oaks stems >5 feet are stump sprouts.

New oak reproduction—Establishment of new oak reproduction after the shelterwood treatments was erratic and varied greatly among stands and plots within stands. Although some new oak seedlings were inventoried during each measurement, most of the new oak seedlings were associated with the good local acorn crops of 1980, 1986, and 1987. Nine-year oak seedling establishment ranged from 500 to 7,000 per acre and averaged 1,640 per acre on medium sites (site index 10) and 2,170 in site index 75 stands. Northern red and black oak made up 50 percent of the new oak stems in site index 60 stands and 95 percent in site index 75 stands. The amount of new oak reproduction was not related to site quality, overstory density, or understory control.

Mortality of oak reproduction—Mortality of pretreatment oak reproduction occurred throughout the 9-year period but the greatest losses were associated with the drought of 1980 when 30 percent of the original oak stems died the first year after treatment. Over the 9-year period, mortality of original oak stems was not significantly influenced by site quality or overstory stocking but was strongly affected by understory density control. Loss of original oak stems was 50 percent in stands receiving the intensive treatment, 69 percent in those receiving the partial treatment, and 71 percent in stands with no understory control (table 5). Mortality was primarily concentrated in the stems in the <1-ft height class and only about five percent of the original oak stems >1 ft tall were lost.

Mortality of new oak stems established between 1980 and 1984 was also affected significantly by understory treatments. Losses of new oak stems in stands receiving the intensive and partial control treatments were about the same averaging 20 and 32 percent, respectively. Mortality of new oak stems in stands receiving no understory treatment averaged more than 50 percent (table 5). Mortality in terms of number of stems was greatest for the red oaks, but losses in terms of percent of total stems were about the same for red oaks and white oak for each understory treatment.

Oak regeneration stocking values—Although the shelterwood treatments applied in this study resulted in an increase in the numbers of oak stems >1 ft tall over those in the pretreatment stands, abundance of advance reproduction alone is not a good indicator of whether oaks will be a major component of a new stand after harvest. Reproduction size and distribution should also be considered in evaluating oak regeneration potential. Site quality should also be considered because height growth of competing species will be greater on the more productive sites.

Sander and others (1984) developed a procedure to evaluate the regeneration potential for oak advance reproduction on upland sites in the Missouri Ozarks. The method evaluates the probability of individual oak reproduction stems becoming dominants or codominants at new stand age 20 years. An oak stocking value of 30 for reproduction in the present stand will develop to C-level stocking in the new stand at age 20 years.

Subsequent research indicated that the 1984 prediction system produced very conservative estimates of oak stocking values for upland stands in the Missouri Ozarks. Consequently, a comprehensive regeneration simulator was developed for more reliable regeneration prediction in the Ozark Highlands Region (Dey and others 1996). Although the new system is recommended for regeneration prediction in the Missouri Ozarks, the more conservative method

Table 5—Mortality of original and new oak reproduction as affected by understory treatment

Understory treatment	Original oak reproduction[a]			New oak reproduction[b]		
	Mortality	Error mean square	P>F	Mortality	Error mean square	P>F
Number of stems						
1[c]	1,014			249		
2	1,365	1.49E6	0.88	387	1.58E5	0.27
3	1,278			521		
Percent of total						
1[c]	50			20		
2	69*[d]	3.26E2	.01	32	4.03E2	.01
3	71*			53*		

[a] Original oak reproduction present before treatment.
[b] New oak reproduction established after treatment.
[c] 1 = All stems treated; 2 = stems >5 ft treated; 3 = no treatment.
[d] Mortality values in columns followed by * are significantly different ($\alpha = 0.05$).

Table 6—Calculated oak stocking values for oak reproduction present before treatment and 5 and 9 years after treatment as affected by understory treatment

Year	Oak stocking value[a]/understory treatment[b]			Error mean square	P>F
	1	2	3		
	- - - - - - -Mean stocking values (x10) - - - - - - -				
1979	12.72	16.36	11.36	9.01E1	0.1149
1984	39.70*[c]	57.42**	19.15	3.62E2	.0004
1988	72.31*	97.26*	26.18	1.18E3	.0002

[a] Stocking value is the contribution of oak reproduction to future stand stocking at stand age 20 years (Sander and others 1984).
[b] 1 = All stems treated; 2 = stems >5 ft treated; 3 = no treatment.
[c] Understory means in rows followed by * or ** are significantly different at $\alpha = 0.05$ and 0.01, respectively.

Sander and others 1984) was used to predict oak stocking values for the Boston Mountain stands in this study. The 1996 Missouri Ozark system was developed for a physiographic region having a different array of major competing understory species and a lower density of competing stems than are common to upland stands on medium and good quality sites in the Boston Mountains.

Calculated oak stocking values for pretreatment stands demonstrate that oak advance reproduction in present undisturbed upland oak stands on medium and good sites is currently inadequate to ensure a significant oak component in the new stands after harvest (table 6). While the mean oak stocking value for all plots averaged 1.4, stocking values averaged 2.1 (range = 0.5 to 3.2) on medium sites and a mean of 0.6 (range = 0.1 to 2.2) on good sites. After treatment, stocking values increased on all plots but stocking values 5 and 9 years after treatment were significantly greater in stands receiving the partial and intensive understory control treatments (table 6). Stands receiving partial treatment produced the greatest initial response, but after 9 years, the stocking values of stands receiving the partial and intensive treatments did not differ significantly. Overstory stocking did not affect oak stocking values. Plots cut to 40 percent overstory density produced average stocking values of 5.6 while stands cut to 60 percent averaged 7.5. Site quality did not significantly affect oak stocking values but the difference between medium and good sites should be silviculturally significant. Plots in site index 60 stands receiving the intensive and partial treatments produced oak stocking values of 11.0 and 14.6, respectively.

Plots on the good oak sites (site index 75) had oak stocking values of 3.5 and 4.9 for intensive and partial treatments, respectively. Based on calculated stocking values for advance reproduction in stands on medium sites with the intensive and partial treatments would require approximately 140 and 115 stump sprouts per acre, respectively, to attain the 30 percent stocking goal. Stands on site index 75 with complete and partial treatments would require about 195 and 185 sprouts per acre, respectively, to reach the 30 percent stocking value (Sander and others 1984). Predicted stump sprouting for residual stands in this study would average only about 20 per acre.

Ash and cherry reproduction will supplement the deficiency in oak stocking and will result in adequate stocking in stands on medium sites. However, on good sites, predicted stocking values for oak, ash, and cherry reproduction would still be less than one-half the recommended target. On both medium and good upland sites, the overstory treatments with partial or intensive understory control significantly increased the numbers of oak, ash, and cherry stems between 1 and 5 ft in height over the 9-year period. Graney and Murphy (1995) found that oak, ash, and cherry reproduction in the 1- to 5-ft classes produced the greatest response to the understory treatments. Thus, the first treatment developed a pool of advance reproduction that is now in the height range to produce a significant height growth response to a second understory treatment. A second understory treatment is especially required on the good sites.

MANAGEMENT IMPLICATIONS

On medium and good upland sites in the Boston Mountains, oak advance reproduction is plentiful, but most oak stems are too small to successfully compete with less-desirable species after harvest. Consequently, the overall regeneration potential of the oaks is inadequate. Overstory thinning plus removal of midcanopy stems >1.6 in. d.b.h. increases growth of oak advance reproduction >3 ft tall, but few stems of this size are present in these mature upland stands. To enhance development of existing small stems and ensure survival and growth of new oak stems established after treatment, intensive understory treatment will be required. Removal of all or most of the competing understory will be necessary if oaks initially 1 to 2 ft tall are to survive and attain adequate size before final overstory removal. In fact, two understory treatments may be required to insure adequate numbers of large stems in these upland stands on medium sites and will certainly be required on good upland sites. Understory treatments can be done chemically or mechanically or by using fire. Treatment by fire may be desirable because it would mimic disturbance dynamics of the past.

Small ash and cherry reproduction is also stimulated by intensive understory control, and one treatment would appear sufficient. Large advance ash and cherry reproduction require only overstory and midcanopy density reduction to compete successfully with other reproduction.

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